

# An upgraded issue of the parton and hadron cascade model, PACIAE 2.2

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## Abstract

The parton and hadron cascade model PACIAE 2.1 (cf. Comput. Phys. Commun. 184 (2013) 1476) has been upgraded to the new issue of PACIAE 2.2. By this new issue the lepton-nucleon and lepton-nucleus (inclusive) deep inelastic scatterings can also be investigated. As an example, the PACIAE 2.2 model is enabled to calculate the specific charged hadron multiplicity in the  $e^-+p$  and  $e^-+D$  semi-inclusive deep-inelastic scattering at 27.6 GeV electron beam energy. The calculated results are well comparing with the corresponding HERMES data. Additionally, the effect of model parameters  $\alpha$  and  $\beta$  in the Lund string fragmentation function on the multiplicity is studied.

*Keywords:* relativistic nuclear collision; (inclusive) deep inelastic scattering, PYTHIA model; PACIAE model.

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## PROGRAM SUMMARY

*Manuscript Title:* An upgraded issue of the parton and hadron cascade model, PACIAE 2.2

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*Program Title:* PACIAE version 2.2

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*Licensing provisions:* none  
*Programming language:* FORTRAN 77  
*Computer:* DELL Studio XPS and/or others with a FORTRAN 77 compiler  
*Operating system:* Linux with FORTRAN 77 compiler  
*RAM:*  $\approx$  1G bytes  
*Number of processors used:*  
*Supplementary material:*  
*Keywords:* relativistic nuclear collision; (inclusive) deep inelastic scattering; PYTHIA model; PACIAE model.  
*Classification:* 11.1, 17.8  
*External routines/libraries:*  
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*Journal reference of previous version:* Ben-Hao Sa, Dai-Mei Zhou, Yu-Liang Yan, Bao-Guo Dong, and Xu Cai, *Comput. Phys. Commun.* 184(2013)1476.  
*Does the new version supersede the previous version?:* Yes  
*Nature of problem:* The lepton inclusive and semi-inclusive deep inelastic scattering (DIS and SIDIS) off nuclear target have greatly contributed to the parton structure of hadron, the parametrization of parton distribution function (PDF), and the extraction of fragmentation function (FF). Unfortunately, the PACIAE 2.1 model is unable to describe the lepton-nucleon and lepton-nucleus DIS (SIDIS), the corresponding upgrade is highly required.  
*Solution method:* The parton and hadron cascade model of PACIAE 2.1 is upgraded to PACIAE 2.2 with the possibility of investigating the lepton-nucleon and lepton-nucleus DIS (SIDIS). In the PACIAE 2.2 model the lepton-nucleon and lepton-nucleus DIS are treated the same as proton-nucleon and proton-nucleus collisions in PACIAE 2.1, respectively. However, the lepton-nucleon DIS cross section is used instead of the nucleon-nucleon cross section in the initiation stage of the PACIAE model.  
*Reasons for the new version:* In order that the PACIAE 2.2 model is now also able to simulate the lepton-nucleon and lepton-nucleus DIS.  
*Summary of revisions:* In the PACIAE 2.2 model the lepton-nucleon and lepton-nucleus DIS are dealt with the same way as the proton-nucleon and proton-nucleus collisions in PACIAE 2.1, respectively. However, the lepton-nucleon DIS cross section is employed instead of nucleon-nucleon cross section.  
*Restrictions:* Depend on the problem studied.  
*Unusual features:* none  
*Additional comments:* Email addresses: sabh@ciae.ac.cn (B.-H. Sa), yanyl@ciae.ac.cn (Y.-L. Yan).  
*Running time:* PACIAE 2.2 has three versions of PACIAE 2.2a, 2.2b, and 2.2c.

*PACIAE 2.2a is for the elementary collision, such as  $pp$ ,  $\bar{p}p$ , and  $e^+e^-$  collisions, as well as the lepton-nucleon DIS, with input file of `usux.dat`. PACIAE 2.2b and PACIAE 2.2c are for the nuclear-nucleus collision of  $p+A$  and  $A+B$  as well as the lepton-nucleus DIS with input file of `usu.dat`. PACIAE 2.2b and 2.2c are similar in the physical contents but are different in the topological structure (see text for the details).*

- *Using the attached input file of `usux.dat` to run 1000 events for the  $\sqrt{s}=200$  GeV Non Single Diffractive  $pp$  collision by PACIAE 2.2a spends 0.5 minute.*
- *Using the attached input file of `usu.dat` to run 10 events for the 10-40% most central Au+Au collisions at  $\sqrt{s_{NN}}=200$  GeV by PACIAE 2.2b spends 4 minutes.*
- *Using the attached input file of `usu.dat` to run 10 events for the 10-40% most central Au+Au collisions at  $\sqrt{s_{NN}}=200$  GeV by PACIAE2.2c spends 8 minutes.*

## 1. Introduction

The lepton inclusive and semi-inclusive deep inelastic scattering (DIS and SIDIS) off nuclear target are the most active frontiers between nuclear and the particle physics since the eighties of the last century. They have greatly contributed to the parton structure of hadron [1], the parametrization of parton distribution function (PDF) [2, 3], and the extraction of polarization-averaged fragmentation function (FF) [4, 5]. They also play important role in the hadronization of initial partonic state and the space-time evolution of the fragmentation process [5].

Two new electron ion collider (EIC) programs of the eRHIC at BNL and ELIC at Jefferson Laboratory (JLab) are evolved in the USA [6]. They are aimed at reaching the highly variable center of mass (cms) energies of  $\sim 20 - 150$  GeV and the high collision luminosity of  $\sim 10^{33-34} \text{ cm}^{-2}\text{s}^{-1}$ . Meanwhile, a similar program of LHeC is also progressed at CERN in Europe [7]. The collision cms energy and luminosity of LHeC may achieve  $\sim 1$  TeV and  $\sim 10^{33}\text{cm}^{-2}\text{s}^{-1}$ , respectively. Both the eRHIC (ELIC) and LHeC are able to yield great insight into the nucleon structure, such as how partons share the spin, mass, and magnetic moment of a nucleon, etc. To confront this expected new DIS era, an upgraded PACIAE 2.2 model, being able to investigate the l-p and l-A DIS, is introduced.

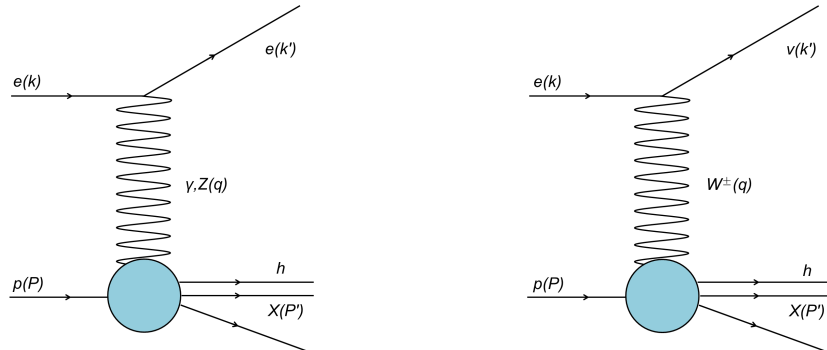


Figure 1: (color online) Lowest order (Born approximation) Feynman diagram of the neutral current (NC) and charged current (CC) electron DIS.

For a reliable extraction of the FF with the quark fragmentation function of  $D_q^h$  distinguished from the antiquark ones of  $D_{\bar{q}}^h$ , the data of specific charged hadron ( $\pi^+$ ,  $\pi^-$ ,  $K^+$ ,  $K^-$ ) multiplicity in the unpolarized SIDIS are highly needed [4, 8]. Recently, the HERMES collaboration has measured the multiplicity of charged pions and kaons in the 27.6 GeV electron beam SIDIS off proton and deuteron [8]. As an example, the PACIAE 2.2 model is employed calculating the DIS normalized  $\pi^+$ ,  $\pi^-$ ,  $K^+$ , and  $K^-$  multiplicities in the above electron SIDIS off proton and the deuteron. The calculated results are well comparing with the corresponding HERMES data [8].

We have given a summary for the history of the PACIAE model in introduction section of the first long writing-up paper of PACIAE 2.0 [9]. Since then, the most important progresses are:

- The net-proton, net-baryon, and net-charge multiplicity nonstatistical fluctuations in the relativistic nuclear collisions are successfully investigated in [10, 11].
- We have updated the PACIAE model from PACIAE 2.0 to PACIAE 2.1 [12] by randomly sampling the  $p_x$  and  $p_y$  components of hadrons, generated in the string fragmentation, on a circumference of ellipse with half major and minor axes of  $p_T(1 + \delta_p)$  and  $p_T(1 - \delta_p)$  instead of on a circle with radius  $p_T$  originally. The PACIAE 2.1 model has been successfully employed studying systematically the elliptic flow parameter in the relativistic nuclear collisions at RHIC and LHC energies [13].

The paper is organized as follows: After the introduction of section I the PACIAE model and its new content of the lepton-nucleon DIS are briefly presented in section II. Here it is distinguished that the PACIAE 2.2 model has three versions of PACIAE 2.2a, 2.2b, and 2.2c. For the elementary collisions of  $pp$ ,  $\bar{p}p$ , and  $e^+e^-$  as well as the lepton-nucleon DIS, PACIAE 2.2a should be used together with the input file of `usux.dat`. PACIAE 2.2b and PACIAE 2.2c are used for the nuclear-nucleus collisions of  $p+A$  and  $A+B$  as well as the lepton-nucleus DIS with the input file of `usu.dat`. PACIAE 2.2b is similar to PACIAE 2.2c in the physical contents but is different in the topological structure (see later for the details). The results are given in section III. In the section IV a brief conclusions are drawn.

## 2. Models

The PACIAE model [9, 12] is based on PYTHIA [14]. However, the PYTHIA model is for high energy elementary collisions ( $e^+e^-$ , lepton-hadron, and hadron-hadron ( $hh$ ) collisions) only, but PACIAE is also for lepton-nucleus DIS and nuclear-nucleus collisions ( $p+A$  and  $A+B$ ). In the PYTHIA model a  $hh$  collision, for instance, is decomposed into parton-parton collisions. The hard parton-parton collision is described by the LO-pQCD parton-parton interactions with the modification of parton distribution function in a hadron. The soft parton-parton collision, a non-perturbative process, is considered empirically. The initial- and final-state QCD radiations as well as the multiparton interactions are taken into account. So the consequence of a  $hh$  collision is a partonic multijet state composed of diquarks (anti-diquarks), quarks (antiquarks), and gluons, besides a few hadronic remnants. It is followed by the string construction and fragmentation, thus a final hadronic state is obtained for a  $hh$  ( $pp$ ) collision finally.

In the PACIAE model [9, 12], the nucleons in a colliding nucleus are first randomly distributed according to the Woods-Saxon distribution in the spatial coordinate space. The participant nucleons, resulted from Glauber model calculation, are required to be inside the overlap zone, formed when two colliding nuclei path through each other at a given impact parameter. The spectator nucleons are required to be outside the overlap zone but inside the nucleus-nucleus collision system. If the incident beam is in the  $z$  direction, we set  $p_x = p_y = 0$  and  $p_z = p_{beam}$  for the projectile nucleons,  $p_x = p_y = p_z = 0$  for the target nucleons in the laboratory framework as well as  $p_x = p_y = 0$  and  $p_z = -p_{beam}$  for the target nucleons in the collider framework.

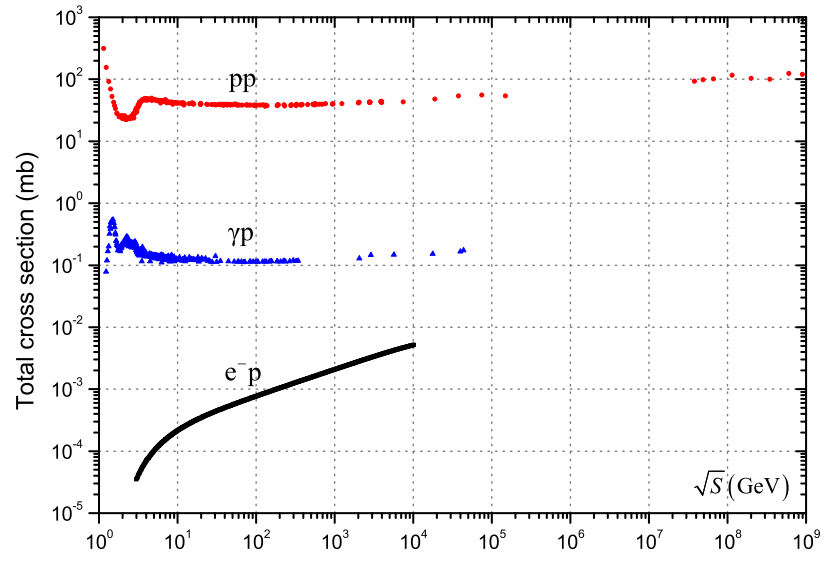


Figure 2: (color online)  $pp$ ,  $\gamma p$ , and  $e^-p$  (DID) total cross sections.

We then decompose a nucleus-nucleus collision into nucleon-nucleon ( $NN$ ) collisions according to nucleon straight-line trajectories and the  $NN$  total cross section. Each  $NN$  collision is dealt by PYTHIA with the string fragmentation switched-off and the diquarks (anti-diquarks) broken into quark pairs (anti-quark pairs). A partonic initial state (composed of the quarks, antiquarks, gluons, and a few hadronic remnants) is obtained for a nucleus-nucleus collision after all of the  $NN$  collision pairs were exhausted.

This partonic initial stage is followed by a parton evolution stage. In this stage the parton rescattering is performed by the Monte Carlo method with  $2 \rightarrow 2$  LO-pQCD cross sections [15]. The hadronization stage follows the parton evolution stage. The Lund string fragmentation model and a phenomenological coalescence model are provided for the hadronization. However, the string fragmentation model is selected in these calculations. The rescattering among produced hadrons is then dealt with the usual two body collision model [9, 12]. In this hadronic evolution stage, only the rescatterings among  $\pi$ ,  $K$ ,  $\rho(\omega)$ ,  $\phi$ ,  $p$ ,  $n$ ,  $\Delta$ ,  $\Lambda$ ,  $\Sigma$ ,  $\Xi$ ,  $\Omega$ , and their antiparticles are considered for simplicity.

As the same as PACIAE 2.0 and 2.1, PACIAE 2.2 also has three versions of PACIAE 2.2a, 2.2b, and 2.2c. PACIAE 2.2a describes the relativistic elementary collisions of  $pp$ ,  $\bar{p}p$ ,  $e^+e^-$ , and lepton-nucleon DIS with input file of `usux.dat`. PACIAE 2.2b and PACIAE 2.2c describe the relativistic nuclear-nucleus collisions of  $p+A$  and  $A+B$  as well as lepton-nucleus DIS. In the PACIAE 2.2b model the partonic initiation, partonic evolution (rescattering), hadronization, and the hadronic evolution (rescattering) are performed for each  $hh$  collision pairs independently until all the  $hh$  collision pairs are collided. Oppositely, in the PACIAE 2.2c, the partonic initiation is first performed for all the  $hh$  collision pairs. This full initial partonic state is proceeded to the partonic evolution stage, then the hadronization stage, and at last the hadronic evolution stage. Therefore, PACIAE 2.2b and 2.2c are similar in the physical contents but are different in the topological structure.

For  $p+p$  and  $p+A$  ( $A+p$ ) collisions, the overlap zone is not introduced presently. We deal the  $l+p$  and  $l+A$  DIS like the  $p+p$  and  $p+A$  collisions, respectively, but instead of the nucleon-nucleon cross section the lepton-nucleon DIS cross section is used. In the PYTHIA model, the  $e^-+p$  ( $e^++p$ ),  $\mu^-+p$  ( $\mu^++p$ ), and  $\tau^-+p$  ( $\tau^++p$ ) DIS have two options of ' $e^-$ ' (' $e^+$ '), ' $\mu^-$ ' (' $\mu^+$ '), and ' $\tau^-$ ' (' $\tau^+$ ') as well as ' $gamma/e^-$ ' ( $gamma/e^+$ ), ' $gamma/\mu^-$ ' (' $gamma/\mu^+$ '), and ' $gamma/\tau^-$ ' (' $gamma/\tau^+$ '), respectively, in the specification of beam and target particle. However, the neutrino-nucleon (antineutrino-

nucleon) DIS has only the first option. In order to be more consistent and to have a better running stability the first option is chosen for all the lepton-nucleon DIS in the PACIAE 2.2 model.

Fig. 1 shows the leading order (Born approximation) Feynman diagrams for the neutral current (NC, the exchange of  $\gamma/Z$  boson, left panel) and charged current (CC, the exchange of  $W^\pm$  boson, right panel)  $e^- + p$  DIS. There are two vertices in the left panel of Fig. 1, for instance. At the upper boson vertex the initial state QED and weak radiations have to be considered. At the lower boson vertex, not only the leading order parton level process of  $V^*q \rightarrow q$  ( $V^*$  refers to  $\gamma/Z/W$ ) but also the first order QCD radiation of  $V^*g \rightarrow qg$  as well as the boson-gluon fusion process of  $V^*g \rightarrow q\bar{q}$  have to be considered. Furthermore, the parton shower approach has been introduced to take higher than first order QCD effects into account [16]. Therefore the DIS cross section can be formally expressed as

$$\sigma_{NC(CC)} = \sigma_{NC(CC)}^{Born} (1 + \delta_{NC(CC)}^{qed}) (1 + \delta_{NC(CC)}^{weak}) (1 + \delta_{NC(CC)}^{qcd}) \quad (1)$$

[17], where  $\sigma_{NC(CC)}^{Born}$  is the Born cross section,  $\delta_{NC(CC)}^{qed}$ ,  $\delta_{NC(CC)}^{weak}$ , and  $\delta_{NC(CC)}^{qcd}$  are, respectively, the QED, weak, and the QCD radiative corrections.

In the lowest-order perturbative QCD theory, the NC/CC DIS Born cross section of the unpolarized electron on an unpolarized nucleon can be expressed by the structure functions  $F_1, F_2, F_3$  as follows [18]

$$\frac{d^2\sigma^I}{dx dy} = \frac{4\pi\alpha^2}{xyQ^2} \eta^I \left( \left( 1 - y - \frac{x^2 y^2 M^2}{Q^2} \right) F_2^I + y^2 x F_1^I \mp \left( y - \frac{y^2}{2} \right) x F_3^I \right), \quad (2)$$

where the mass of the incident and scattered leptons are neglected. In the above equation,  $I$  denotes  $NC$  or  $CC$ .  $\alpha$  stands for the fine structure constant.  $x \equiv x_B$  and  $y$  are the Bjorken scaling variable and fraction energy of  $\gamma/Z/W$  boson, respectively.  $Q^2$  is the negative squared 4-momentum transfer.  $M$  refers to the mass of target nucleon.  $\eta^{NC} = 1$ ,  $\eta^{CC} = (1 \pm \lambda)^2 \eta_W$ , and

$$\eta_W = \frac{1}{2} \left( \frac{G_F M_W^2}{4\pi\alpha} \frac{Q^2}{Q^2 + M_W^2} \right) \quad (3)$$

$$G_F = \frac{e^2}{4\sqrt{2}\sin^2\theta_W M_W^2}, \quad (4)$$

where  $M_W$  and  $\theta_W$  are the mass of  $W$  boson and the Weinberg angle, respectively.  $\lambda = \pm 1$  is the helicity of the incident lepton.



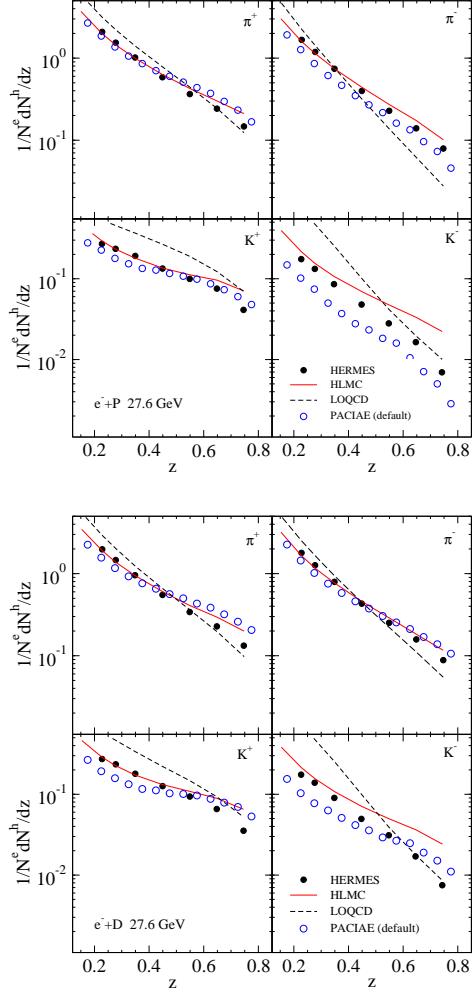


Figure 3: (color online) Multiplicity of DIS normalized specific charged hadron as a function of  $z$  in the  $e^-+p$  (upper panel) and  $e^-+D$  (lower panel) DIS at 27.6 GeV electron beam energy.

The structure functions above can be expressed by the parton distribution function of nucleon in the quark-parton model [19]. Presently we can not calculate PDF from the first principles and PDF can only be extracted from the QCD fits with a measure of the agreement between the experimental data of lepton-nucleon DIS cross sections and the theoretical models [20]. With the PDFs at hand, we are able to calculate the lepton-nucleon DIS cross section. The black curve in Fig. 2 gives the unpolarized  $e^-+p$  DIS total cross section calculated with HERAPDF1.5 LO PDF set [21]. In the calculation [22] the cuts are first set for  $Q^2 > 1$  GeV and  $W^2 > 1.96$  GeV ( $W^2$  is the squared invariant mass of the photon-nucleon system) and then the cuts in  $x$  and  $y$  are derived according to the relationships among kinematic variables and  $\cos^2\theta \leq 1$ . The red and blue data points in Fig. 2 are, respectively, the total cross section of  $pp$  and  $\gamma p$  collisions copied from [18].

One knows well that the incident proton, in the  $p+Au$  collisions at RHIC energies for instance, may collide with a few ( $\sim 2-5$ ) nucleons when it passes through the gold target. Since the  $e^-+p$  DIS total cross section is a few order of magnitude smaller than the  $pp$  collision at the range of  $\sqrt{s} < 1000$  GeV (cf. Fig. 2), one may expect that the incident electron, in this energy range, may suffer at most one DIS with the nucleon when it passes through the target nucleus. The struck nucleon is the one with lowest approaching distance from the incident electron. This is the same for other incident leptons because the lepton-nucleon DIS total cross section is not so much different among the different leptons [22].

Therefore in the pioneer studies [23] for the lepton-nucleus DIS by PYTHIA + BUU transport model, the FRITIOF 7.02 [24] or PYTHIA 6.2 [25] was employed to generate a lepton-nucleon DIS event. The generated hadronic final state was then input into the BUU (Boltzmann-Uehling-Uhlenbeck) equation [26] considering the final state hadronic interaction (hadronic rescattering). This PYTHIA + BUU transport model successfully described the HERMES data of the ratio of DIS normalized charged hadron multiplicity in the lepton-A (nucleus) DIS to the one in the lepton-deuteron DIS, for the 27.5 GeV electron beam energy  $e^++^{14}\text{N}$  and  $e^++^{84}\text{Kr}$  DIS [27].

### 3. Results

As mentioned in [8, 28] the measured hadron multiplicity in SIDIS has first to be corrected for the radiative effects, the limitations in geometric acceptances, and the detector resolution. The Born-level multiplicity is then

obtained. Therefore, the DIS (total yield) normalized Born-level multiplicity of the  $h$  type hadrons as a function of  $z$  (the fractional energy of hadron  $h$ ) in the lepton SIDIS off a nuclear target can be expressed as

$$\frac{1}{N_{DIS}} \frac{dN^h}{dz} = \frac{1}{N_{DIS}} \int d^5 N^h(x_B, Q^2, z, P_{h\perp}, \phi_h) dx_B dQ^2 dP_{h\perp} d\phi_h \quad (5)$$

[8], where  $N_{DIS}$  refers to the DIS total yield,  $P_{h\perp}$  is the component of the hadron momentum  $P_h$  transverse to  $q$  (the 4-momentum of the mediator  $\gamma/Z/W$ ) and  $\phi_h$  stands for the azimuthal angle between the lepton scattering plane and the hadron production plane. Thus one may compare the calculated  $\frac{1}{N_{DIS}} \frac{dN^h}{dz}$  in the full kinematic phase space with the HERMES data, like done in [8, 28].

In the PACIAE 2.2 model simulations, the model parameters are all fixed the same as the default values given in PYTHIA. Figure 3 gives the comparison of the HERMES  $\frac{1}{N_{DIS}} \frac{dN^h}{dz}$  data (solid circles) [8] to the corresponding results of the PACIAE 2.2 model (open circles), HLMC (solid line), and the LOQCD (dashed line). Here HLMC refers to the HERMES Lund Monte Carlo. HLMC is a combination of the DIS event generator Lepto [16] based on JETSET 7.4 and PYTHIA 5.7 [29], the detector simulation program based on GEANT [30], and the HERMES reconstruction program [28]. The HLMC results in Fig. 3 were calculated with fitting thirteen model parameters to the multiplicity as a function of  $z$ ,  $p_T$  (transverse momentum), and  $\eta$  (pseudorapidity) of the  $\pi^-$ ,  $K^-$ , and  $\bar{p}$  [28]. The LOQCD results in Fig. 3 were calculated in the framework of collinear factorization at the leading order perturbative QCD [8, 31]. In Fig. 3 one sees that the default PACIAE fairly well reproduces the HERMES data.

Table 1: DIS normalized multiplicity of  $\pi^+$ ,  $\pi^-$ ,  $K^+$ , and  $K^-$  in the  $e^-+p$  DIS.

Effect of $\alpha$ with default $\beta=0.58$					Effect of $\beta$ with default $\alpha=0.3$				
$\alpha$	$\pi^+$	$\pi^-$	$K^+$	$K^-$	$\beta$	$\pi^+$	$\pi^-$	$K^+$	$K^-$
0.2	1.331	0.9591	0.1164	0.04406	0.39	1.355	0.9834	0.1204	0.04828
0.3	1.339	0.9666	0.1177	0.04646	0.58	1.339	0.9666	0.1177	0.04646
0.45	1.351	0.9785	0.1196	0.04732	0.87	1.315	0.9419	0.1132	0.04161

Meanwhile, the effect of  $\alpha$  and  $\beta$  parameters in the Lund string fragmentation function [14]

$$f(\hat{z}) \propto \frac{1}{\hat{z}} (1 - \hat{z})^\alpha \exp\left(-\frac{\beta m_T^2}{\hat{z}}\right) \quad (6)$$

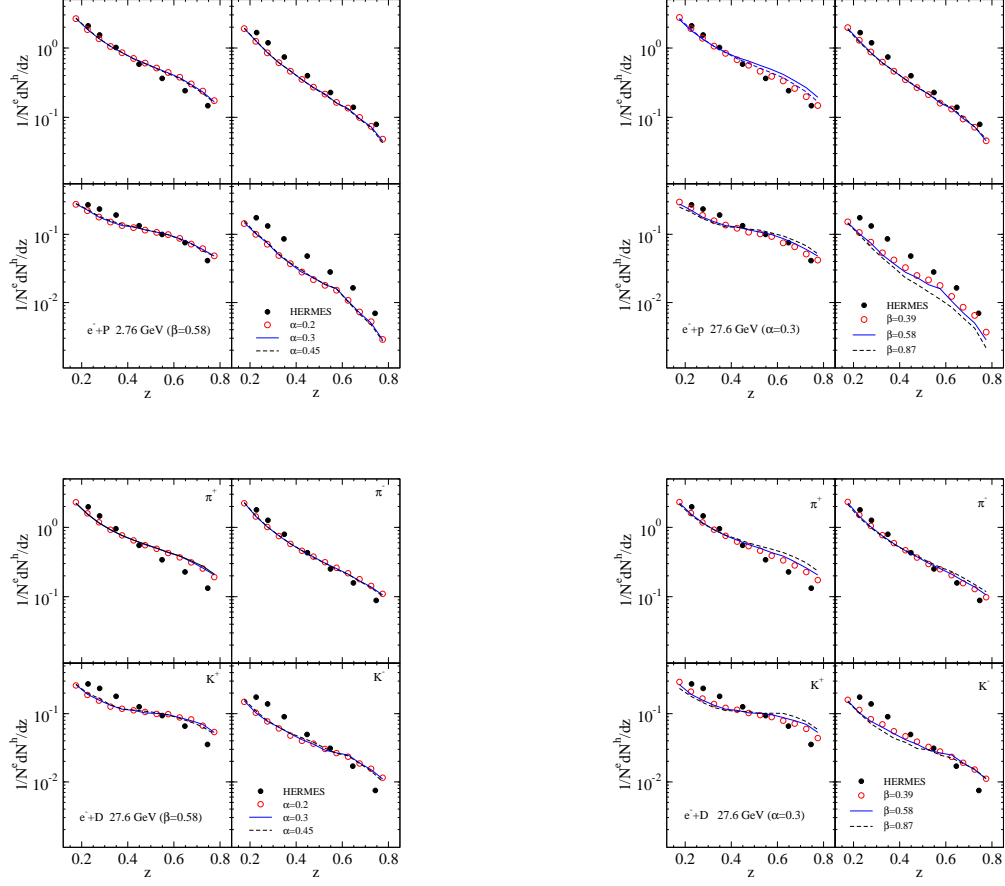


Figure 4: (color online) The effect of parameter  $\alpha$  (left panels) and  $\beta$  (right panels) in the Lund string fragmentation function on  $\frac{1}{N_{DIS}} \frac{dN^h}{dz}$  in the  $e^-+p$  (upper panels) and  $e^-+D$  (lower panels) DIS at 27.6 GeV electron beam energy.

Table 2: DID normalized multiplicity of  $\pi^+$ ,  $\pi^-$ ,  $K^+$ , and  $K^-$  in the  $e^-+D$  DIS.

Effect of $\alpha$ with default $\beta=0.58$					Effect of $\beta$ with default $\alpha=0.3$				
$\alpha$	$\pi^+$	$\pi^-$	$K^+$	$K^-$	$\beta$	$\pi^+$	$\pi^-$	$K^+$	$K^-$
0.2	1.314	1.364	0.1203	0.05538	0.39	1.351	1.407	0.1269	0.06116
0.3	1.326	1.383	0.1219	0.05696	0.58	1.326	1.383	0.1219	0.05696
0.45	1.345	1.399	0.1239	0.05919	0.87	1.288	1.342	0.1161	0.05192

on the multiplicity is investigated. In the above equation  $\hat{z}$  refers to the fraction lightcone variable taken by the fragmented hadron out of the fragmenting particle and  $m_T^2 = p_T^2 + m_0^2$  where  $m_0$  refers to the rest mass of the fragmented hadron. The results are given in the tables 1 and 2 as well as in figure 4. We see here that the multiplicity increases (decreases) with  $\alpha$  ( $\beta$ ) increasing. The effect shown in the differential observable  $\frac{1}{N_{DIS}} \frac{dN^h}{dz}$  is weak but visible, as shown in Figs 4.

#### 4. Conclusions

In summary, we have upgraded the the parton and hadron cascade model PACIAE 2.1 to a new issue of PACIAE 2.2 involving the lepton-nucleon and lepton-nucleus DIS. The PACIAE 2.2 is then employed investigating the DIS normalized specific charged hadron multiplicity as function of  $z$ ,  $\frac{1}{N_{DIS}} \frac{dN^h}{dz}$ , in the 27.6 GeV electron beam energy  $e^-+p$  and  $e^-+D$  SIDIS. The PACIAE 2.2 results calculated with default parameters reproduce fairly well the corresponding HERMES data [8].

Additionally, we have investigated the effect of model parameters  $\alpha$  and  $\beta$  in the Lund string fragmentation function. It turned out that the particle multiplicity increases (decreases) with  $\alpha$  ( $\beta$ ) increasing. The effect on the global observable of yield is not small, but on the differential observable of  $\frac{1}{N_{DIS}} \frac{dN^h}{dz}$  is just visible. These effects are expected to be increased with increasing reaction energy and system size.

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#### References

- [1] Xiangdong Ji, Nucl. Phys. B **402**, 217 (1993).
- [2] R. Placakyte, arXiv:1111.5452 v4 [hep-ph].
- [3] Klaus Rith, arXiv:1402.5000v1.
- [4] E. Leader, A. V. Sidorov, and D. B. Stamenov, arXiv:1312.5200v1.

- [5] A. Airapetian, et al., HERMES Collaboration, Nucl. Phys. B **780**, 1 (2007).
- [6] White paper writing committee, Electron ion collider: The next QCD frontier, arXiv:1212.1701v2 [nucl-ex].
- [7] LHeC study group, A Large Hadron electron Collider at CERN, arXiv:1206.2913 [physics.acc-ph]; arXiv:1211.4831v1 [hep-ex].
- [8] A. Airapetian, et al., HERMES Collaboration, Phys. Rev. D **87**, 074029 (2013).
- [9] Ben-Hao Sa, Dai-Mei Zhou, Yu-Liang Yan, Xiao-Mei Li, Sheng-Qin Feng, Bao-Guo Dong, and Xu Cai, Comput. Phys. Commun. **183**, 333 (2012).
- [10] Dai-Mei Zhou, Ayut Limphirat, Yu-Liang Yan, Yun Cheng, Yu-Peng Yan, Xu Cai, Laszlo P. Csernai, and Ben-Hao Sa, Phys. Rev. C **85**, 064916 (2012).
- [11] Dai-Mei Zhou, Zeng-Zeng Luo, Yun Cheng, Ayut Limphirat, Yu-Liang Yan, Yu-Peng Yan, Xu Cai, and Ben-Hao Sa, J. Phys. G: Nucl. Part. Phys. **41**, 065013 (2014).
- [12] Ben-Hao Sa, Dai-Mei Zhou, Yu-Liang Yan, Bao-Guo Dong, and Xu Cai, Comput. Phys. Commun. **184**, 1476 (2013).
- [13] Ben-Hao Sa, Dai-Mei Zhou, Yu-Liang Yan, Yun Cheng, Bao-Guo Dong, and Xu Cai, Phys. Lett. B **731**, 87 (2014).
- [14] T. Sjöstrand, S. Mrenna, and P. Skands, JHEP **05**, 026 (2006).
- [15] B. L. Combridge, J. Kripfgang, and J. Ranft, Phys. Lett. B **70**, 234 (1977).
- [16] G. Ingelman, A. Edin, and J. Rathsman, Comput. Phys. Commun. **101**, 108 (1997).
- [17] C. Adloff, et. al., H1 Collaboration, Eur. Phys. J. C **19**, 269 (2001).
- [18] Review of Particle Physics, Phys. Rev. D **86**, 1 (2012).
- [19] J. D. Bjorken and E. A. Paschos, Phys. Rev. **185**, 1975 (1969); R. P. Feynman, Photon hadron interactions, Benjamin, New York, 1972.

- [20] A. Gizhko, HERAFitter, Nucl. Phys. B, Proceedings Supplements, 2013, 245: 161-163 (<http://herafitter.org>); M. R. Wysley, D. Bourilkov, and R. C. Group, arXiv: hep-ph/0508110v1.
- [21] H1 and ZEUS Collaborations, H1prelim-13-141 and ZEUS-prel-13-003.
- [22] Xing-Long Li, Yu-Liang Yan, Xiao-Mei Li, Dai-Mei Zhou, Xu Cai, and Ben-Hao Sa, Systematic study of the differential and total cross sections as well as the final hadron multiplicity in the lepton-nuclear collisions, in preparation.
- [23] T. Fatler, W. Cassing, K. Gallmeister, and U. Mosel, Phys. Lett. B **594**, 61 (2004); T. Fatler, W. Cassing, K. Gallmeister, and U. Mosel, Phys. Rev. C **70**, 054609 (2004); K. Gallmeister, and U. Mosel, Nucl. Phys. A **801**, 68 (2008).
- [24] Hong Pi, Comput. Phys. Commun. **71**, 173 (1992).
- [25] T. Sjöstrand, et. al., Comput. Phys. Commun. **135**, 238 (2001).
- [26] T. Fatler, K. Gallmeister, and U. Mosel, Phys. Rev. C **67**, 054606 (2003).
- [27] HERMES Collab., Eur. Phys. J. C **20**, 479 (2001); V. Muccifora, HERMES Collab., Nucl. Phys. A **771**, 254c (2002).
- [28] A. Hillenbrand, Ph.D. thesis: DESY-THESIS-2005-035, 2005.
- [29] T. Sjöstrand, Comput. Phys. Commun. **82**, 74 (1994).
- [30] R. Brun, R. Hagelberg, M. Hansroul, and J. C. Lassalle, GEANT: Simulation program for particle physics experiments. User guide and reference manual, (1978), CERN-DD-78-2 Rev.
- [31] S. Kretzer, Phys. Rev. D **62**, 054001 (2000).